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TRANSIENT PROTECTION, GROUNDING, BONDING AND SHIELDING REQUIREMENTS FOR ELECTRONIC EQUIPMENT

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FOREWORD

This FAA standard sets forth requirements for the application of transient protection, grounding, bonding, shielding and personnel protection practices to the design, fabrication and assembly of electronic equipment. The electromagnetic interference (EMI) requirements related to these disciplines are also provided. This standard shall be applied to new electronic equipment or as modifications are made to existing electronic equipment.

This standard contains 6 sections. Section 1 states the scope of the standard and gives its purpose. Section 2 lists the reference documents. Section 3 gives requirements for transient protection, grounding, bonding, shielding and personnel protection. Section 4 provides Quality Assurance requirements. Section 5 provides Preparation for delivery information. Section 6 contains notes and definitions.

The use of "shall" in this document indicates a requirement. It is understood that in certain cases it may not be technically feasible to implement certain requirements. In these cases exemptions shall be documented as part of contract documents or in the equipment drawings.

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1. SCOPE

1.1 Scope. This document defines standard configurations and procedures, for transient protection, grounding, bonding, shielding and personnel protection, for new electronic equipment used to support air traffic control functions. In addition, it may be used as reference information, without imposing minimum or mandatory requirements for existing electronic equipment.

1.2 Purpose. The requirements of this standard are intended to minimize electrical hazards to personnel and minimize damage to equipment due to lightning, transients, and power faults, and also to minimize electromagnetic interference.

2. APPLICABLE DOCUMENTS

2.1 Government documents. Issues of the following documents in effect on the date of an invitation-for-bid or request-for-proposals, form a part of this standard. They are applicable only to the extent specified herein. If conflicts occur between these referenced documents and this standard, the standard shall provide the superseding requirement.

FAA Specifications:

FAA-G-2100	Electronic Equipment, General Requirements

FAA Standards:

FAA-STD-019	Lightning Protection, Grounding, Bonding and Shielding Requirements for Facilities
FAA-STD-012	Paint Systems for Equipment

FAA Orders:

Order 6950.19	Practices and Procedures for Lightning Protection, Grounding, Bonding and Shielding Implementation.
Order 6950.20	Fundamental Considerations of Lightning Protection, Grounding, Bonding & Shielding.

(Copies of these specifications, standards, orders and other applicable FAA documents may be obtained from the Contracting Officer issuing the invitation-for-bids or request-for-proposals. Requests should fully identify material desired, i.e. specification, standard, amendment, drawing numbers and dates. Requests should cite the invitation-for-bids, request-for-proposals, the contract involved, or other use to be made of the requested material.)

Military Standards and Handbooks:

DOD-HDBK-263	Electrostatic Discharge Control Handbook
DOD-STD-1686	Electrostatic Discharge Control Program for Protection of Electrical and Electronic Parts, Assemblies and Equipment (Excluding Electrically Initiated Explosive Devices)
MIL-HDBK-237	Electromagnetic Compatibility/Interference Program Requirements

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MIL-HDBK-253	Guidance for Design and Test of Systems Protected Against Effects of Electromagnetic Energy
MIL-STD-461	Electromagnetic Interference Characteristics, Requirements for Equipments
MIL-STD-889	Dissimilar Metals

(Single copies of Military specifications, standards, and handbooks may be requested by mail or telephone from the Naval Forms and Publications Center, 5801 Tabor Ave, Philadelphia PA 19120. Not more than five items may be ordered on a single request; the Invitation for Bid or Contract Number should be cited where applicable. Only latest revisions (complete with latest amendments) are available; slash sheets must be individually requested. Request all items by document number. For subscription service information, direct inquiries to the above address with additional marking (ATTN: CODE 56.)

2.2 Non-Government documents. Refer to para. 2.1, Government Documents.

National Fire Protection Association (NFPA)

NFPA 70	National Electrical Code (NEC)
NFPA 77	Static Electricity

(Requests for copies of the National Electrical Code should be addressed to the National Fire Protection Association, Batterymarch Park, Quincy, MA 02269.)

3. REQUIREMENTS

3.1 Surge and transient protection requirements. Electrical and electronic equipment shall be protected against conducted and radiated surges and transients from all power, signal, control and/or status lines. Integrated circuits, transistors, diodes, solid state voltage regulators, capacitors, miniature relays, miniature switches, and miniature transformers, etc. are quite susceptible to damage and operational upset caused by transients.

3.2 Existing electronic equipment designs. For existing electronic equipment designs, transient suppression specified, may be at line entrances to electronic equipment enclosures, racks, or cabinets, or externally mounted to electronic equipment enclosures using proper grounding, bonding, and shielding procedures.

3.3 Installation by others. Electronic equipment that is not being installed by the manufacturer or supplier shall be provided with all items of material required for installation of transient protection, including complete installation and checkout instructions.

3.4 Electronic equipment transient susceptibility levels. The manufacturer shall perform analyses or tests to determine the voltage, current, or energy levels that will cause immediate damage to components, shortened its operating life, or cause operational upset. These analyses or tests shall consider all electrical and electronic equipment components exposed to the effects of surges or transients. The combined facility and equipment entrance protection shall be coordinated so as to limit transients at the equipment entrance to below the equipment susceptibility level. Requirements of this paragraph

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shall be included in the comprehensive control and test plans outlined in para. 4. In all cases the following characteristics shall be evaluated:

(a) Component damage threshold. The damage threshold is the transient parameter level that renders the component nonfunctional or operationally deficient. For solid state components, voltage is usually the relevant parameter.

(b) Component degradation level. The transient voltage or energy level that, with repeated application, shortens the useful life of the component.

(c) Operational upset level. The transient voltage or energy level that causes an unacceptable change in operating characteristics for a duration in excess of 10 milliseconds for analog equipment or a change of logical state for digital equipment.

3.5 Conducted power input line transients. Transient suppression devices, components or circuits shall be provided at the entrance of AC power conductors to the equipment where needed as an integral part of electronic equipment design. Transient suppression shall be provided equally for both neutral and phase (hot) conductors and shall protect in both the differential and common modes. Electronic equipment that is to be installed outside of facilities shall also require protection to the level supplied for the facility. (See FAA-STD-019, para. 3.7, Conducted powerline surges.)

3.5.1 Surge levels. Surge levels and number of occurrences for life cycle design of transient suppression are given in Table I. In Table I, the 10-by-20 microsecond (μs) waveform defines a surge with a risetime of 10 μs from zero to peak value that exponentially decays to 50 percent of peak value 20 μs after start of the surge. These devices shall be able to tolerate surges of shorter duration without malfunction.

TABLE I. LINE-TO-GROUND SURGE LEVELS FOR 120 VAC POWERLINES

Surge Amplitude 10-by-20 μs Waveform	Number of Surges (Lifetime)
500V, 50A	1,000
750V, 100A	100
1kV, 200A	50

3.5.2 Protection design. A typical configuration for protection of electronic equipment from conducted powerline surges and transients is illustrated in Figure 1, "Typical Configuration for Protection of Electronic Equipment from Conducted Powerline Surges and Transients." Selection of components shall be as follows:

(a) The inductor L1 shall be selected to safely limit the transient current conducted by the varistor, RV1.

(b) The varistor, RV1, shall be selected to limit surge voltages safely below the equipment circuit susceptibility level. The varistor (zinc or metal oxide nonlinear resistor) shall have adequate current and energy ratings to safely conduct the surge levels listed in Table I. A varistor is illustrated as the

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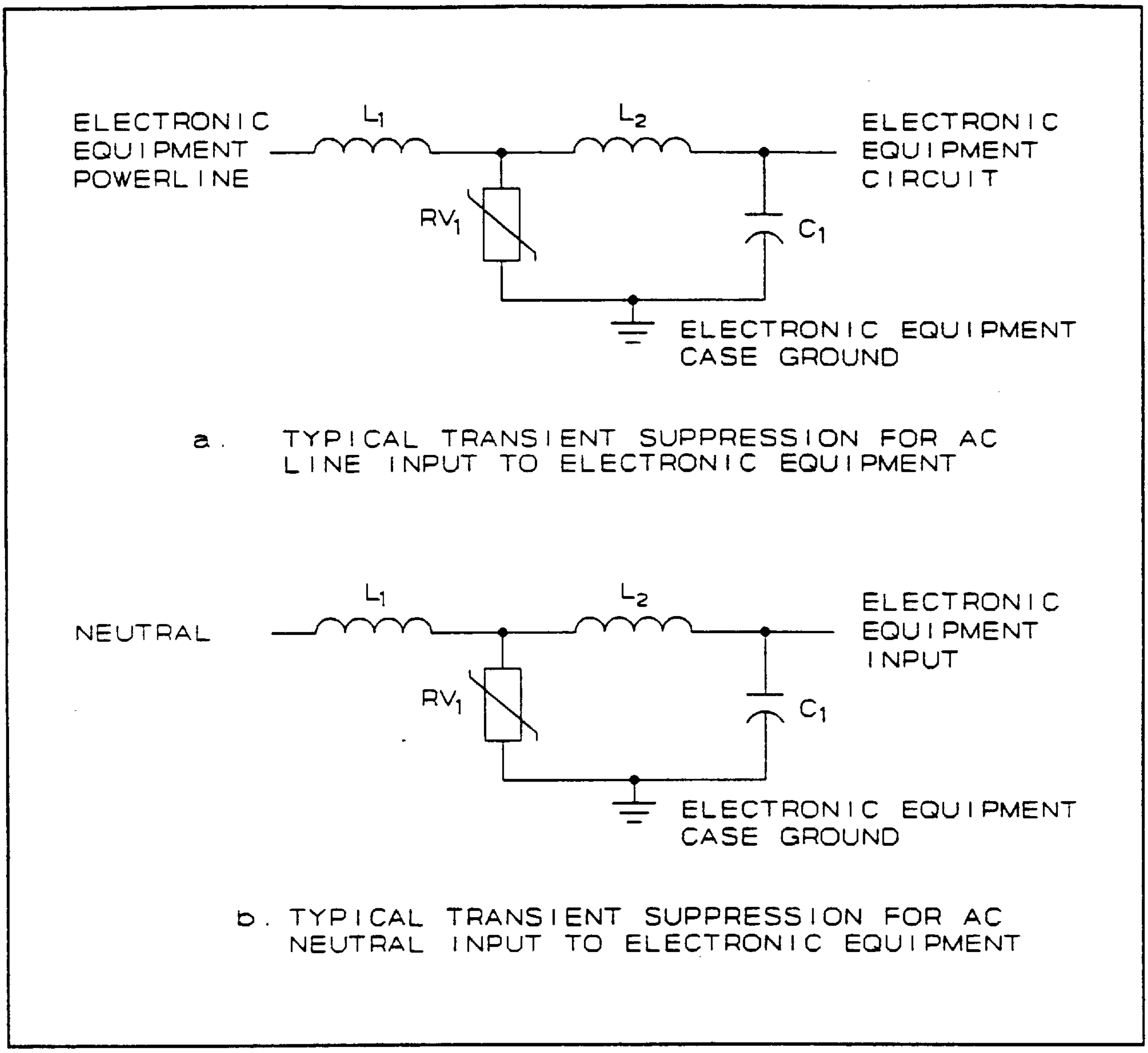

Figure 1. Typical Protection Configurations for Electronic Equipment from Conducted Powerline Surges and Transients.

suppression circuit device in Figure 1 because the characteristics of available devices are suitable for many applications. Other suppression devices, such as silicone avalanche diode suppressors (SAS), shall be used when their characteristics are better suited to specific applications. Protection of highly susceptible electronic equipment circuits may also require the parallel connection of two or more suppression devices, matched within one percent, or the addition of a second device separated by a properly sized inductor.

(c) The inductor L2 and capacitor C1 limit high frequency transient energy. Selection of these components may also consider the interference and susceptibility requirements of other specifications or standards.

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3.5.3 Functional requirements. The basic characteristics of surge suppression components or circuits for equipment powerlines shall be as follows:

(a) Operating (reverse standoff) voltage. Reverse standoff voltage of the arrester shall be 125 ± 5 percent of the normal line voltage.

(b) Turnon voltage. Turnon voltage, discharge (clamp) voltage, and the amplitude and time duration of any overshoot voltage shall be sufficiently low to preclude electronic equipment damage or operational upset.

(c) Leakage current. Leakage current for each suppression component at reverse standoff voltage shall not exceed 100 microamperes.

(d) Self-restoring capability. The surge suppressors shall automatically restore to an off state when surge voltage falls below the turnon voltage for the suppressor.

(e) Operating lifetime. Electronic equipment surge suppression shall be capable of safely dissipating the number and amplitude of surges specified in Table I. Clamp voltage shall not change more than 10 percent over the operating lifetime.

(f) In-line devices. Only inductors designed to have low DC resistance shall be used as in-line devices for suppression of conducted powerline surges. In-line inductors shall safely pass equipment operating voltages and line current with 130 percent over-voltage conditions for a period of 50 milliseconds. Inductors shall safely handle the number of events at the voltages and currents as listed in Table I.

3.5.4 Packaging. Suppression components shall be housed in a separate, shielded, compartmentalized enclosure as an integral part of the electronic equipment design. Bulkhead-mounted feedthrough capacitors shall be used as necessary to prevent high frequency transient energy from coupling to electronic equipment circuits. Suppression components shall be grounded to the electronic equipment case as directly as feasible.

3.6 Power supply transient suppression. Power supplies that use 60 hertz (Hz) power and furnish operating voltages (5 to 48 VDC) to solid state equipment shall have transient suppression components installed line-to-ground at the power supply rectifier output. During conduction of transients, the suppressor shall not decrease rectifier output voltage below normal. The ground side of suppressors shall be connected as directly as possible to rectifier output ground. Operating characteristics of suppression components provided for power supply rectifier output lines shall be as follows:

(a) Operating (reverse standoff) voltage. Reverse standoff voltage shall be 5 percent above maximum rectifier output voltage.

(b) Leakage current. Leakage current to ground shall not exceed 100 microamperes at reverse standoff voltage.

(c) Turnon voltage. Turnon voltage shall be as near reverse standoff voltage as possible using state-of-the-art suppressors, and shall not exceed 125 percent of standoff voltage.

(d) Discharge (clamp) voltage. Clamp voltage shall be the lowest possible value that can be obtained using state-of-the-art suppressors not exceeding 160 percent of standoff voltage.

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(e) Overshoot voltage. Overshoot voltage shall be sufficiently low to preclude electronic equipment damage or operational upset. Time duration of overshoot voltage shall be limited to the shortest possible time not exceeding 2 nanoseconds.

(f) Self-restoring capability. Transient suppressors installed in power supplies shall automatically restore to an off state when line transient voltage falls below rated turnon voltage for the suppressor.

(g) Operating lifetime. The transient suppressors shall safely dissipate 1000 surges with an amplitude of 200 volts above rectifier output voltage and a waveform of 10-by-20 μs. Ten (10) μs defines the time from the start of the transient to peak voltage, and 20 μs is the time from the start of the transient until the transient decays to 50 percent of peak value.

3.7 Conducted landline transients. Transient protection shall limit transients at the equipment entrance to below the equipment susceptibility level. Landlines include all signal, control, status and interfacility powerlines installed above and below grade between facility structures and to externally mounted electronic equipment. Additional protection requirements applicable to audio, radio frequency (RF) and other signals transmitted by coaxial, twin-axial and tri-axial cables are given in the following subparagraphs.

3.7.1 Transient levels. Electronic equipment using landlines shall be protected against the transient levels defined in Table II. The 10-by-1000 μs wave shape in Table II defines transients with a 10 μs risetime with decay to 50 percent of peak voltage in 1000 μs.

TABLE II. CONDUCTED LANDLINE TRANSIENT LEVELS

Transient Amplitude 10-by-1000 μs waveform	Number of Surges (Lifetime)
100V, 50A	1,000
500V, 100A	100
750V, 375A	50
1000V, 1000A	5

3.7.2 Location of transient protection. The location of transient protection for landlines is specified both at entrances to facilities and at entrances to electronic equipment within facilities. Depending on the type of electronic equipment and planned facility installation, combining the transient suppression specified at facility and electronic equipment entrances may be acceptable. Transient protection designs for landlines which combine the protection specified herein for installation at one location shall (1) provide high-energy suppression component(s) or device(s) connected from line to the facility earth grounding system to remove a major percentage of transient energy from each line, (2) provide low-energy suppression components connected from line to electronic equipment case ground to reduce transient energy and voltages to safe levels below the electronic equipment susceptibility level for each line, (3) be located at the entrance to the facility, and (4) have FAA approval prior to implementation.

3.7.3 Protection design. Detailed analysis of the characteristics of suppression components and electronic equipment circuits is required to select

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component parameters and design suppression circuits that will function properly without adversely affecting signals and information transmitted by individual landlines. Typical configurations for protection of electronic equipment from conducted landline transients are illustrated in FAA-STD-019, Figure 1, "Typical Configurations for Protection for Electronic Equipment from Conducted Landline Transients." Design requirements for the selection of components for landline transient suppression are as follows:

(a) Unipolar or bipolar suppression components shall be selected and installed in the proper direction for signals and voltages that are always positive, always negative, or both positive and negative relative to reference ground.

(b) The maximum landline length for all signals shall be expressed with the transient suppression components required by para. 3.7 installed at each end.

(c) Protection components at facility entrances (varistor in the illustrated configurations) shall be coordinated with the protection at electronic equipment entrances to clamp or limit transients below electronic equipment susceptibility levels.

(d) Resistor R1, shall only be used to limit the transient current conducted by the suppression component at electronic equipment entrances when the conductor does not do so. The resistance of R1, shall be of sufficient value to ensure that the transient voltage at the facility entrance will turn on the facility entrance suppressor before the rated current level of the electronic equipment entrance suppressor is exceeded.

(e) The electronic equipment entrance suppressor, varistor or SAS, shall be selected to clamp and limit the transient voltage and energy safely below the equipment circuit susceptibility levels.

(f) When the lowest voltage device available (such as an SAS) will not adequately limit the transient voltage to electronic equipment circuits, a properly sized resistor, R2, is required to further reduce transient voltages.

(g) Capacitor C1 shall be selected in conjunction with the necessary or desired value of R2 to attenuate high frequency transient energy.

3.7.4 Functional requirements. The combined operating characteristics for landline transient suppression at facility and electronic equipment entrances, and requirements for individual devices shall be as follows:

(a) Reverse standoff voltage. The operating or reverse standoff voltage rating of the suppression component shall be 20 ± 5 percent above normal line voltage or the next higher voltage device available.

(b) Turnon voltage. Turnon voltage of the suppression component at the electronic equipment shall be as close to reverse standoff voltage as possible using state-of-the-art devices, and shall not exceed 125 percent of reverse standoff voltage.

(c) Overshoot voltage. Overshoot voltage shall be low enough to preclude electronic equipment damage or operational upset. The requirement shall apply for transients with rise times as fast as 5,000V/μs.

(d) Clamp (discharge) voltage. Clamp voltage shall be below the electronic equipment susceptibility levels while dissipating the transients listed in Table II.

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(e) Operating life. The transient suppression shall be capable of safely dissipating the transients defined in Table II. Clamp voltage shall not change more than 10 percent over the operating life.

(f) Self-restoring capability. The transient suppression shall automatically restore to the off state when the transient voltage level drops below turnon voltage for the suppressors.

3.7.5 Installation at facility entrance. High energy transient suppression components shall be provided in an enclosed metal junction box immediately after building or shelter entrance. When landlines terminate at a junction box provided by others, a separate junction box shall be provide for installation of suppression components. A ground bus bar, electrically isolated from the enclosure, shall be provided in the junction box to serve as an earth ground for the high energy transient suppressor. The ground bus bar shall be directly connected to the earth electrode system with an insulated No. 4 AWG stranded copper wire of minimum length and no loops, sharp bends or kinks. The wire insulation shall be 600 volts minimum color coded green with a red tracer. An approved connector shall be used to bond the wire to the ground bus bar. The bonding connection to the earth electrode system shall be an exothermic weld or an FAA approved pressure connection. The ground bus bar location shall permit a short, direct connection to transient suppressors. The installation shall provide easy access to component terminals for visual inspection, test, and replacement. Each suppression device shall be replaceable, or as a minimum, the suppressor and resistor for each line shall be replaceable as a unit.

3.7.6 Installation at the electronic equipment. Low-energy suppression components installed at the electronic equipment shall be an integral part of the electronic equipment design, or mounted in an adjacent separate metal enclosure. Bulkhead mounted, feedthrough capacitors shall be used as necessary to prevent high frequency transient energy from coupling to electronic equipment circuits. Component leads shall be of minimum length with no loops, sharp bends or kinks. Suppression component grounds shall be connected directly to the metal enclosure. The enclosure shall be directly bonded to the electronic equipment case (electronic multipoint ground.) Access shall be provided for visual inspection and replacement of components.

3.7.7 Externally mounted equipment. When landlines are directly connected to electronic equipment mounted on the exterior of a facility (or which constitutes the facility), landline suppression specified in this document for facility and electronic equipment entrances shall be provided at the equipment entrance. This combined protection shall provide separate high and low energy components and grounding paths. The high energy suppression component shall be grounded directly to the earth electrode system. This connection shall be accomplished with a minimum #4 AWG insulated copper conductor. This conductor shall be color coded green with a red stripe. The low energy suppression component shall be grounded to the reference ground used by the circuit to which the landline is connected, or to the multipoint ground system. If the connection is made to the multipoint ground system, external to the equipment chassis, it shall use a #6 AWG insulated copper conductor color coded green with an orange stripe. The grounding conducting conductors for the high and low energy components shall be of minimum length and routed to avoid sharp bends, kinks or loops. Access shall be provided for visual inspection of these suppressors and for their replacement.

3.7.8 Axial landlines. Transient protection for electronic equipment using coaxial, tri-axial, and twin-axial landlines (axial-type lines) shall be provided both at facility entrances and at the electronic equipment. Transient suppression shall be provided equally for each conductor and for

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each shield that is not grounded directly to the electronic equipment case. The protection provided for electronic equipment using coaxial, tri-axial and twin-axial landlines shall comply with the requirements given in paragraphs 3.7 through 3.7.7 and the following additional requirements.

3.7.8.1 Protection design. Special attention shall be given to the design of transient protection for axial-type lines. Design may be particularly critical at RF frequencies. The following design requirements apply:

(a) Suppression circuits shall be designed using state-of-the-art components which have minimum effect upon the signals being transmitted. The use of varistors in series with RF chokes, and low capacitance SAS's paralleled with selected RF chokes will reduce the effect of suppression circuits on higher frequency signals. Other compensating techniques and components shall be used as necessary.

(b) Packaging of suppression components and circuits shall be designed to minimize the effect on transmitted signals. Feedthrough components, lead less components, or short direct lead connections without bends will improve performance of the suppression circuit and reduce signal degradation.

(c) Analyses and tests shall be performed to assure that suppression components do not degrade signals to an unacceptable degree or cause marginal operation of electronic equipment. Particular attention shall be given to the impedance, insertion loss, phase distortion, and voltage standing wave ratio for RF signals.

(d) When transient protection as specified herein cannot be provided without unacceptable degradation of performance, alternatives shall be submitted in writing and implemented with approval of the Contracting Officer.

3.7.8.2 Metal bulkhead connector plates. A metal bulkhead connector plate shall be provided where axial-type cables first enter a facility. The connector plate shall be a minimum of 1/4 inch thick, and shall be constructed of tin-plated copper or other material compatible with the connectors. The plate or plates shall have the required number and types of feed-through connectors to terminate all the external lines. The connectors shall provide a path to ground for cable shields, except when the shield must be isolated for proper equipment operation. If external and internal cables are of different sizes, the changeover in cable size shall be accomplished by the feed-through connectors at the plate. The connector plate shall be bonded to the earth electrode system with a No. 2/0 AWG copper cable color coded green with a red tracer. Additionally, when building steel is properly bonded to the earth electrode system, the bulkhead connector plate shall be connected to building steel. Exothermic welds or equivalent shall be used for these connections.

3.7.8.3 Installation at facility entrances. Transient suppression components for axial-type cables shall be packaged in a sealed metal enclosure with appropriate connectors at each end to permit in-line installation at the connector plate. The ground connection for varistors or other suppression devices used at facility entrances, but not mounted at the bulkhead plate, shall be isolated from the suppression circuit enclosure. An insulated ground lead shall be brought out of each suppression circuit enclosure and connected to an adjacent bus or tie point. The ground bus shall be isolated from the connector plate and its enclosure, and connected directly to the facility earth electrode system with an insulated (green with a red tracer) No. 4 AWG stranded copper wire. This grounding conductor shall be separate from the grounding conductor mentioned in para. 3.7.8.2. All ground leads and wire shall be as short as possible with no loops, sharp bends or kinks. Bonding to

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the ground bus shall be by FAA approved connectors and to the facility earth electrode system by exothermic welds or equivalent.

3.7.8.4 Installation at electronic equipment entrances. Off-the-shelf suppression components shall be provided as an integral part of electronic equipment design as specified herein for other types of landlines. When electronic equipment without transient suppression is required for the facility, electronic equipment suppression components shall be packaged in a separate enclosure with connectors on each end for in-line connection directly to the equipment. When isolation of the cable shield and connector body is required for electronic equipment operation, suppression component grounds shall be isolated from the component housing and connected directly to the electronic equipment case which is connected to the earth ground structure. All electronic equipment entrances shall be located in a common area, close to the case ground to minimize circulating ground currents on the case.

3.7.9 Fiber optics cable. This standard does not preclude the use of fiber optics cable as a substitute for metallic signal, control and data cables. Where fiber optics cable uses conductive armor, it shall be terminated to the multipoint ground system at the facility entrance. If the cable is internal to the facility, conductive armor shall be terminated to the multipoint ground system at the equipment entrance. The use of fiber optics cable without a conductive shield or armor is permitted.

3.8 Grounding requirements.

3.8.1 General. The grounding of electronic circuits and equipment shall be accomplished to minimize interference levels and hazards to personnel. The facility ground system will be provided in accordance with FAA-STD-019.

3.8.2 Equipment requiring electronic single grounds. Where electronic equipment performance dictates an isolated electronic single-point ground system for proper operation, all the equipment and its installation shall comply with the following:

3.8.2.1 Electronic single-point ground system. The single-point ground system or plane shall be isolated from the electronic equipment case. If a metal chassis is used as the electronic single-point ground, the chassis shall be floated relative to the case. Design practices shall be such that the single-point ground of the electronic equipment can be properly interfaced with other electronic equipment without compromising the system. If necessary, this single-point ground system may be filtered for high frequencies.

3.8.2.2 Input and output signals. The "high" and "low" sides of input and output signals shall be isolated from the electronic equipment case and balanced with respect to the signal reference. Operating and adjusting controls, readouts or indicating devices, protective devices, monitoring jacks and signal connectors shall be designed to isolate both the high and low side of the signal from the case.

3.8.2.3 Electronic single-point ground terminal(s). Insulated single-point ground system terminal(s) shall be provided on each electronic equipment case where an isolated signal reference is required. The single-point ground reference for the internal circuits shall be connected to this terminal. This terminal(s) shall be used to terminate cable shields, and to connect the isolated signal ground of the electronic equipment to the single-point ground system in the facility. A connector pin, a screw or pin on a terminal strip, an insulated stud, jack or feedthrough, or an insulated wire shall be an acceptable terminal when it conforms to the following:

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(a) Each terminal shall be clearly marked, labeled, or coded in a manner that does not interfere with its intended function. These marks, codes, or labels shall be permanently affixed and shall utilize green with yellow stripes. Wire insulation shall be green with a yellow tracer.

(b) Insulated stranded wires shall not be less than No. 12 AWG copper with a length, outside the case, of not less than 1 foot nor greater than 3 feet.

3.8.2.4 Isolation. With all external power, signal and control lines disconnected from the electronic equipment, isolation between the single-point ground system terminals and the case shall not be less than 10 megohms.

3.8.2.5 Electronic signal lines and cables. Electronic signal lines shall be twisted shielded pairs with the shield insulated. Cables consisting of multiple twisted pairs shall have the individual shields isolated from each other. Cables with an overall shield shall have the shield insulated.

3.8.2.6 Termination of individual shields. Shields of pairs of conductors and the shield of cables containing pairs without individual shields shall be terminated in accordance with the following:

(a) The length of unshielded conductors shall not exceed 1 inch. To meet this requirement, the length of shield pigtail may be longer than 1 inch if necessary to reach ground, but shall be kept to a minimum.

(b) Shields terminated outside the electronic equipment shall employ minimum length pigtails between the breakout of the shield and the connection to the bonding halo or ferrule ring, and between the halo or ferrule ring and the shield pin on the connector. The unshielded length of a signal line, outside the electronic equipment case shall not exceed 1 inch with not more than 1/2 inch exposed length as the desired goal.

(c) Shields, individually and collectively, shall be isolated from overall shields of cables bundles and from electronic equipment cases, racks, cabinets, junction boxes, conduit, cable trays, and elements of the electronic multipoint ground system. Except for one interconnection, individual shields shall be isolated from each other. Care shall be exercised to assure this isolation is maintained in junction boxes, patch panels, and distribution boxes throughout the cable run. When an electronic signal line is interrupted, such as in a junction box, the shield shall be carried through. The length of unshielded conductors shall not exceed 1 inch. To meet this requirement the length of shield pigtail may be longer than 1 inch if necessary where grounded, but shall be kept to a minimum.

(d) Circuits and chassis shall be designed to minimize the distance from the connector or terminal strip to the point of attachment of the shield grounding conductor to the electronic signal reference. The size of the wire used to extend the shield to the circuit reference shall be as large as practical but shall not be less than No.16 AWG or the maximum wire size that will fit the connector pin. The use of a common shield ground wire for input and output signals, for both high level and low level signals, for signal lines and powerlines, or for electronic signal lines and control lines shall be avoided.

(e) Nothing in this requirement shall preclude the extension of the shields through the connector or past the terminal strip to individual circuits or chassis if required to minimize unwanted coupling inside the electronic equipment. Where extensions of this type are necessary, overall cable or bundle shields grounded in accordance with para. 3.8.2.7 shall be provided.

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3.8.2.7 Termination of overall shields. Cables that have an overall shield over individually shielded pairs shall have the overall shield grounded to the case at each end and at intermediate points in accordance with the following:

(a) Shields of cables terminated in connectors shall be bonded to the connector shell as shown in FAA-STD-019, Figure 6, "Grounding of Overall Cable Shields to Connectors and Penetrated Walls," a) "Box Connector" or b) "Grounding of Multi-pin Connector." The shield shall be carefully cleaned to remove dirt, moisture, and corrosion products. The securing clamp of the connector shall be carefully tightened to assure that a low resistance bond to the connector shell is achieved completely around the circumference of the cable shield. The bond shall be protected against corrosion in accordance with paragraphs 3.9.5 and 3.9.5.1. The panel-mounted part of the connector shall be bonded to the mounting surface in accordance with para. 3.9.8.

(b) Cables which penetrate walls or panels of cases or enclosures without the use of connectors shall have their shields bonded to the penetrated surface as shown in FAA-STD-019, Figure 6, c) "Partition Penetration."

(c) Grounding of overall shields to terminal strips shall be as shown in FAA-STD-019, Figure 7, "Grounding Overall Shield to Terminal Strip."

(d) Where the cable continuity is interrupted such as in a junction box, the shield shall be carried through and grounded at the equipment box. The length of unshielded conductors shall not exceed 1 inch. To meet this requirement the length of shield pigtail may be longer than 1 inch if necessary to reach the equipment ground, but shall be kept to a minimum.

(e) The shields of the individual pairs shall be grounded as specified in para. 3.8.2.6.

3.8.2.8 Single-point grounding of electronic equipment. Each single-point ground terminal shall be connected to the facility single-point ground system in accordance with the following:

(a) Individual units or pieces of electronic equipment which by nature of their location or function cannot or should not be mounted with other electronic equipment, shall have an insulated copper cable installed between the electronic single-point ground terminal specified in 3.8.2.3 and the nearest electronic single-point ground system ground plate as illustrated in Figure 2, "Single Point Grounding for an Individual Unit or Piece of Electronic Equipment." This cable shall have a cross-sectional area of 500 circular mils per linear foot.

(b) Where two or more units or pieces of electronic equipment are mounted together in a rack or cabinet, a single-ground bus bar shall be installed as shown in Figure 3, "Single Point Electronic Signal ground Bus Bar Installation in Rack or Cabinet." The bus bar shall be copper and shall provide a minimum cross-sectional area of 125,000 square mils. The bus bar shall be drilled and tapped for No. 10 screws. The holes shall be located as required by the relative location of the isolated electronic single-point grounding terminals on the electronic equipment. The bus bar shall be mounted on insulating supports that provide at least 10 megohms DC resistance between the bus bar and the rack or cabinet.

(c) Each electronic equipment isolated single-point ground terminal shall be interconnected to the bus bar by means of a solid or flexible tinned copper jumper of sufficient cross-sectional area so that its resistance is 5 milliohms or less (No.12 AWG minimum.) The jumper shall be insulated or mounted in a manner that maintains the required degree of isolation between

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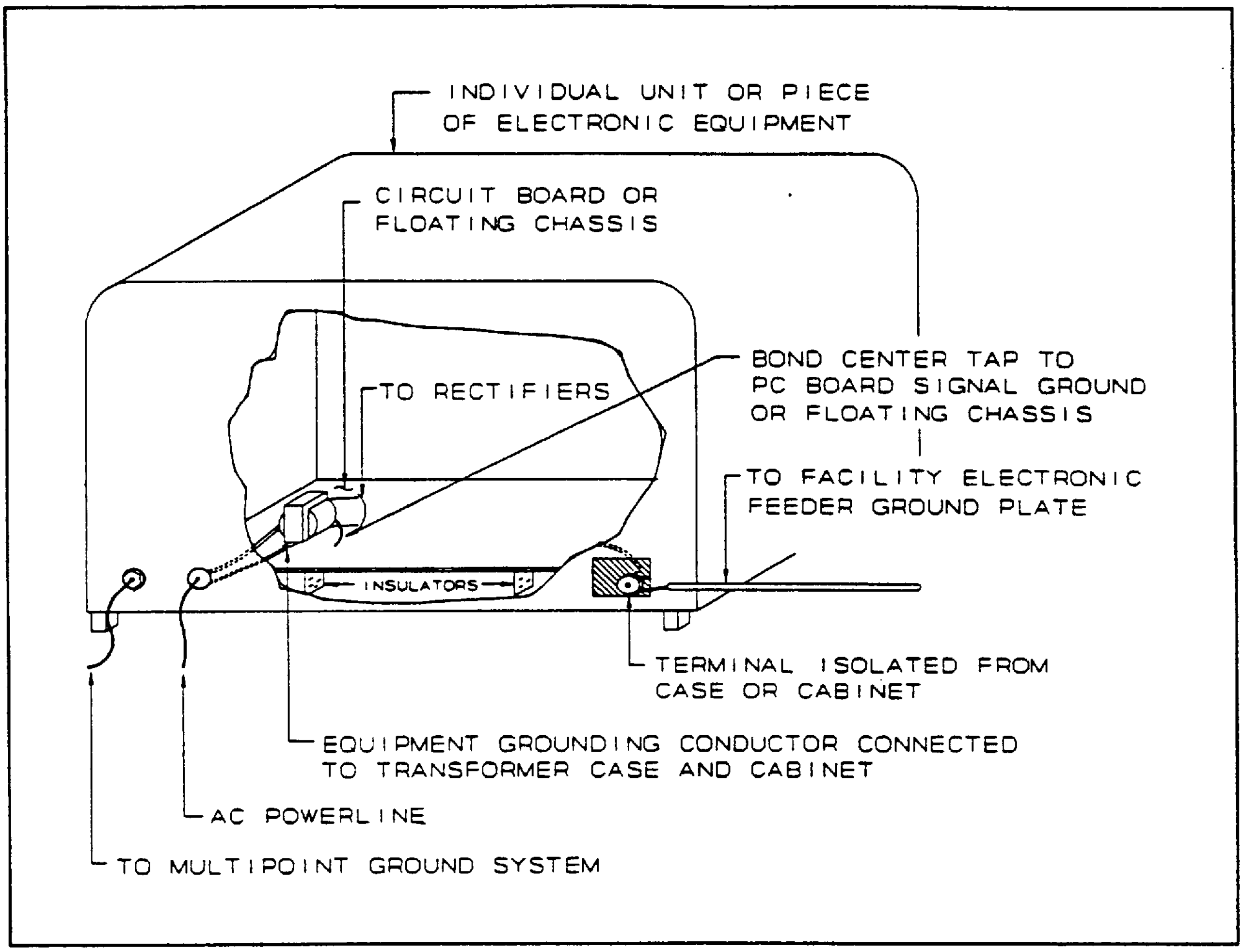

Figure 2. Single Point Grounding for Individual Unit or Piece of Electronic Equipment

the reference conductor and the enclosure. The interconnecting jumper shall be attached to the bus bar at a point nearest to the single-point ground terminal to which the strap is attached. An insulated copper cable shall be installed from the bus bar in the cabinet to the nearest electronic single-point ground system. This cable shall provide at least 500 circular mills per linear foot, and must be No. 16 AWG for up to 5 feet or must be No. 12 AWG for up to 10 feet in length.

3.8.3 Multipoint grounding of electronic equipment. When permitted by circuit design requirements, all internal ground references shall be directly bonded to the chassis and the equipment case. Where mounted in a rack, cabinet or enclosure, the electronic equipment case shall be bonded to the racks, cabinet or enclosure in accordance with para. 3.9.7.2. The DC resistance between any two points within a chassis or electronic equipment cabinet serving as ground shall be less than 25 milliohms total or 2.5 milliohms per joint. Shields shall be provided as required for personnel protection and electromagnetic interference (EMI) reduction.

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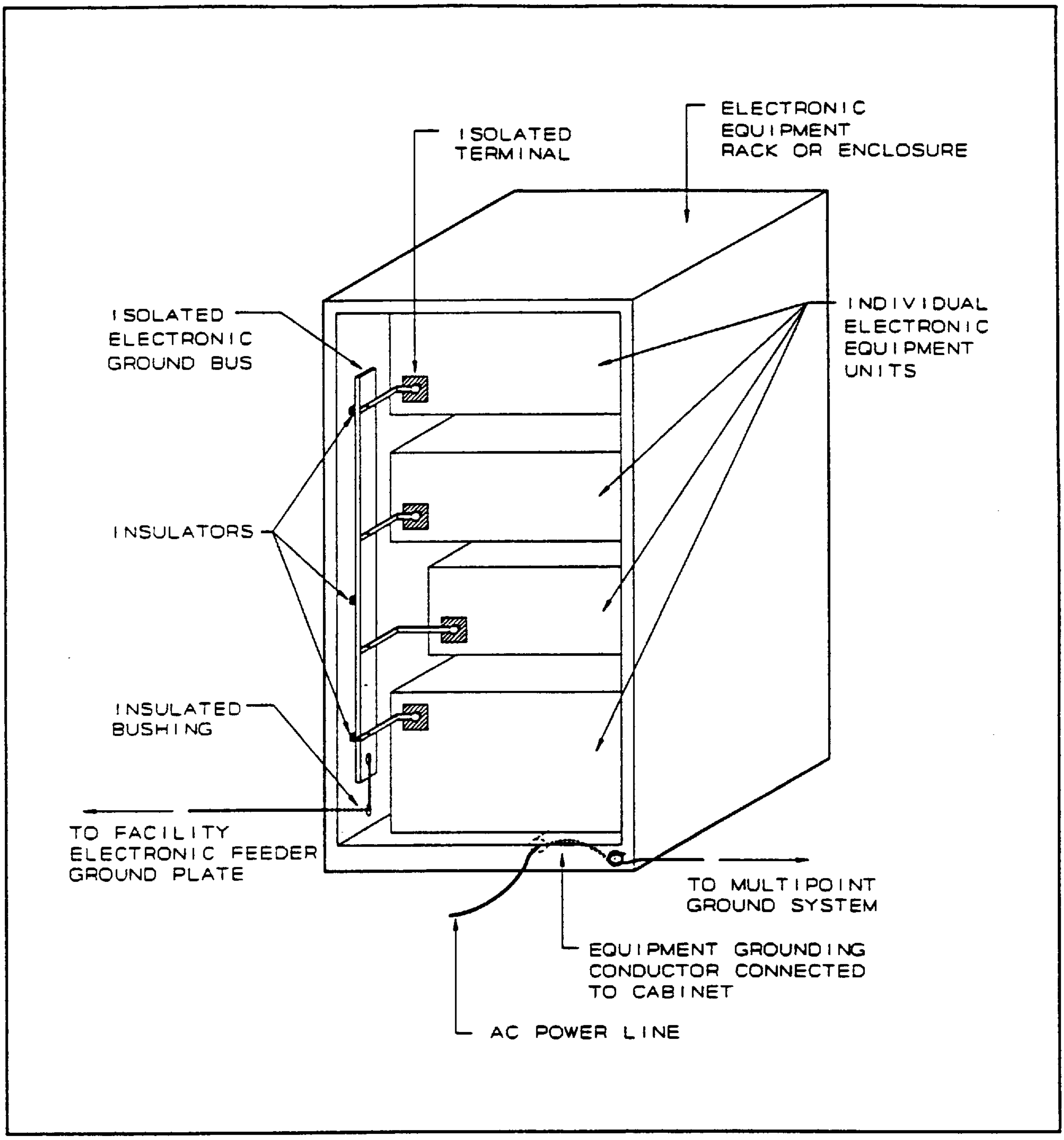

Figure 3. Single Point Electronic Ground Bus Bar Installation in Rack or Cabinet

3.8.3.1 Electronic signal return path. The electronic signal return path shall be routed with the circuit conductor. For coaxial circuits the shield serves this purpose. For multiconductor signal cables, each signal function shall have a return. The electronic equipment case and electronic multipoint ground system shall not be used as a return conductor.

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3.8.3.2 Shield terminations of coaxial and other cables. All connectors shall be of a type and design that provides a low impedance path from the signal line shield to the electronic equipment case. If the electronic signal reference plane must be isolated from the electronic equipment case, and if the shielding effectiveness of the case must not be degraded, a connector of a tri-axial design that properly grounds the outer cable shield to the case shall be used. Shields of coaxial cables and balanced transmission lines shall be terminated by peripherally grounding the shield to the electronic equipment case. Bonding of connectors shall be in accordance with para. 3.9.8. The use of pigtails to terminate high frequency line shields outside the electronic equipment case shall not be permitted. Coaxial shields and connector shells shall be grounded to the electronic multipoint ground system at junction boxes, patch panels, signal distribution boxes, and other interconnection points along the electronic signal path.

3.8.4 Electronic equipment containing both low and high frequency circuits. If the low and high frequency circuits in electronic equipment are functionally independent, and if construction and layout will permit separate electronic signal references, the low frequency circuits may be grounded in accordance with paragraphs 3.8.2 through 3.8.2.8. If the low frequency and high frequency circuits share a common electronic signal reference, both circuits shall be grounded in accordance with paragraphs 3.8.3 and 3.8.3.1.

3.8.4.1 Input and output electronic signals. Where the low-frequency signal reference is separate from the high-frequency signal reference, low-frequency input and output signals shall conform to paragraphs 3.8.2.2 and 3.8.2.4. High-frequency input and output signals shall conform to paragraphs 3.8.3 and 3.8.3.1. Where a common signal reference is used, the low-frequency input and output signals shall be balanced with respect to the signal reference. Extreme care shall be taken to maintain isolation between the single-point ground system and the electronic multipoint ground system, except at the main ground plate or counterpoise.

3.8.5 Electronic cabinet, rack, and case grounding. All electronic cabinets, racks, and cases shall provide a grounding terminal or means whereby a grounding jumper or wire can be mechanically connected through an electrically conductive surface to the basic frame. Each individual unit or piece of electronic equipment shall be grounded to its cabinet or rack, or shall be grounded directly to the electronic multipoint ground system (see FAA-STD-019, para. 3.11, Electronic multipoint ground system requirements) if direct bonding is not possible. All grounding wires shall have a minimum cross-sectional area of 2000 circular mils per linear foot and may not be less than No.12 AWG. This requirement is in addition to the grounding required for compliance with the NEC, NFPA-70.

3.8.5.1 Mounting surfaces. Electronic equipment mounting surfaces on cabinets and racks shall be free of non-conducting finishes. Mounting surfaces for electronic equipment that will be mounted in cabinets or racks shall also be free of non-conducting finishes.

3.8.6 Equipment grounding conductor. Each piece of electrical and electronic equipment shall be grounded where required by the NEC. The equipment grounding conductor shall be a green insulated wire, sized in accordance with the requirements of the NEC, and run in the same access way as its related phase and neutral conductors. Cord connected equipment shall include the equipment grounding conductor as an integral part of the power cord. Where power is supplied to electronic equipment through a cable and connector, the connector shall contain a pin to continue the equipment grounding conductor to the equipment chassis. Conduit or cable shields shall not be used as the equipment grounding conductor.

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3.8.7 Receptacles. Receptacles (convenience outlet) shall be provided with a ground terminal. An equipment grounding conductor whose path is electrically continuous and is in the same raceway or cable as the power conductors feeding the receptacles shall be connected to the ground terminal. Where required for the possible reduction of electrical noise (electromagnetic interference) on the grounding circuit, receptacles shall be permitted in which the grounding terminal is purposely isolated from the receptacle mounting. The receptacle grounding terminal shall be grounded by means of an isolated equipment grounding conductor run with the circuit conductors (phase and neutral.) This grounding conductor shall be permitted to pass through one or more panelboards without connection to the panelboard grounding terminal. This equipment grounding conductor shall terminate directly at the equipment grounding conductor terminal of the applicable derived system or service. A second insulated equipment grounding conductor shall be installed from the metal outlet box housing the receptacle to the panelboard feeding this receptacle. This conductor shall be bonded at one end to the metal outlet box and connected at the other end to the ground bus in the panelboard feeding the isolated ground pin receptacle. All equipment grounding conductors shall be run in the same conduit with their associated phase and neutral conductors.

3.8.8 AC powerline isolation. With the equipment power cord or connector (para. 3.8.6) disconnected, and the equipment power switch or breaker in the ON position, the resistance between each powerline (including AC neutral) and the equipment case and between each powerline and the single-point ground system shall not be less than 10 megohms.

3.8.9 Portable equipment. Portable electrical or electronic equipment cases, enclosures, and housing shall be considered to be adequately grounded for fault protection through the equipment grounding conductor (third wire) of the power cord, provided continuity is firmly established between the case, enclosure or housing, and the receptacle ground terminal. The power cord equipment grounding conductor shall not be used for signal grounding.

3.8.10 Fault protection. Equipment parts such as panels, covers, knobs, switches, and connectors which are subject to human contact during operation and maintenance shall be prevented from becoming electrically energized when there are powerline faults or component failures. Such parts shall be grounded by a low impedance path to the chassis or cases of the equipment on which they are mounted. When grounded in accordance with para. 3.8.6, equipment chassis, cases, racks, cabinets, and other enclosures shall be considered adequately grounded for fault protection.

3.8.10.1 Metal control shafts. Metal control shafts shall be grounded to the equipment case through a low impedance path provided by close-fitting conductive gaskets, metal finger stock, or grounding nuts.

3.8.10.2 Shielded compartments. Shields shall be bonded to the chassis for fault protection in accordance with paragraphs 3.9 through 3.9.11.

3.8.11 Powerline filters. All powerline filter cases shall be directly bonded in accordance with paragraphs 3.9.7.1 and 3.9.7.2 to the equipment case or enclosure. Filter leakage current shall not exceed 5 ma per filter. Where practical and where the equipment is compatible, common powerline filters shall be used to limit total leakage current. Transient suppression devices, components or circuits provided in accordance with paragraphs 3.5 through 3.7 shall be located on the line side of filter components to protect capacitors and other filter components which may be damaged by transients.

3.8.12 Grounding of RF transmission lines and antennas. Antenna and transmission line terminals shall be at ground potential, except for RF energy

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on their external surfaces. This requirement shall be met by providing a DC path from such terminals to ground which are of sufficiently low resistance and heavy current carrying capacity to disable the source of any internal high voltage supply that may be applied to the terminals by accident or failure of some part.

3.9 Bonding requirements.

3.9.1 General. Bonding for electrical purposes shall be accomplished by a method that provides the required degree of mechanical strength, achieves and maintains the low value of low-frequency and high-frequency impedance required for proper functioning of the equipment, and is not subject to deterioration through vibration or corrosion in normal use.

3.9.2 Methods.

3.9.2.1 Welding. When practical, joints, seams, and other metallic interfaces shall be continuously welded. Where metal interfaces are not required to be RF-tight, spot welding shall be adequate.

3.9.2.2 Soldering. Soldered bonds shall be carefully made to prevent cold solder joints. Where there are mechanical loads and stresses, including those resulting from temperature differentials existing at the joint, soldered bonds shall utilize auxiliary fasteners such as bolts, screw, or rivets to provide mechanical strength. Solder connections shall not be used for any part of the power grounding system or the lightning protection system.

3.9.2.3 Bolting. Bolts and machine screws shall be used primarily as mechanical fasteners for holding the component members of the bond in place. They shall be tightened sufficiently to maintain the contact pressures required for effective bonding but shall not be over-tightened to the extent that deformation of bond members occurs. Where lockwashers are required to prevent loosening, they shall not be placed between the bond members. Bolts and screws shall not be used as indirect bonds for high-frequency signals. If the resistance levels of para. 3.9.11 are met, bolts and screws shall be adequate indirect bonds for shock hazard protection of personnel.

3.9.2.4 Riveting. Rivets shall be employed primarily as mechanical fasteners to hold multiple smooth, clean metal surfaces together or to provide a mechanical load bearing capability to a soldered bond. Rivets shall not be used as indirect bonds for high frequency signals. Riveted joints shall be adequate for personnel shock hazard protection provided the resistance requirements of para. 3.9.11 are met.

3.9.2.5 Sheet metal screws. Sheet metal screws shall not be used to provide a continuous and permanent electrical bond. The use of sheet metal screws shall be restricted to the fastening of covers. These covers are to eliminate dust or other foreign matter from the equipment, and to discourage unauthorized or untrained personnel access to the equipment.

3.9.2.6 Bonding straps. Bond straps, including jumpers, shall be as follows:

(a) Bonding straps shall be attached to the basic member rather than through any adjacent parts.

(b) When installed, bonding straps shall be unaffected electrically by motion or vibration.

(c) bonding straps shall be designed not to have resonant impedances at equipment operating frequencies.

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(d) Bonding straps shall be installed whenever possible in areas accessible for maintenance.

(e) Bonding straps shall be installed so they will not restrict movement of the members being bonded or other members nearby which must be able to move as part of their normal functional operation.

(f) Two or more bonding straps shall not be connected in series to provide a single bonding path.

(g) The method of installation and point of attachment of bonding straps shall not weaken the members to which they are attached.

(h) Bonding straps shall not be compression-fastened through non-metallic material.

3.9.3 Surface preparation. All surfaces to be bonded shall be thoroughly cleaned to remove all dirt, grease, oxides, nonconductive films, or other foreign material. Paints and other organic coatings shall be removed by sanding or brushing down to the bare metal. The use of chemical removers shall be acceptable, provided that all residue is removed from the area to be bonded and provided that the chemical does not react with the base metal to produce nonconductive or corrosive products.

3.9.3.1 Machined surfaces. Where an RF-tight joint is necessary, both surfaces shall be machined smooth to provide uniform continuous contact through the joint area and a RF gasket (para. 3.9.10) shall be used to insure a low impedance path across the joint. Fasteners shall be positioned and distributed in a manner that maintains uniform pressure throughout the bond area.

3.9.3.2 Surface platings or treatments. Surface treatments that include platings provided for added wearability or corrosion protection shall offer high conductivity. Plating metals shall be electrochemically compatible with the base metals (para. 3.9.4.) Unless suitably protected from the atmosphere, silver and other easily tarnished metals shall not be used to plate bond surfaces, except where an increase in surface contact resistance cannot be tolerated.

3.9.4 Dissimilar metals. Bonds between dissimilar metals as defined by FAA-STD-019 (Table IV and para. 3.14, Bonding requirements) shall be avoided to the maximum extent possible. Where dissimilar metals are used, an interposing material compatible with each shall be used. MIL-STD-889 provides specific information in this area.

3.9.5 Bond protection. Bonds shall be protected from corrosion and vibration as specified herein. Protective measures shall be applied after the bond has been completed.

3.9.5.1 Corrosion protection. Except for welded or brazed bonds, all exterior and interior bonds exposed to moisture or high humidity shall be protected against corrosion. All interior bonds made between dissimilar metals shall be protected against corrosion in accordance with FAA-STD-019 (Table IV and para. 3.14, Bonding requirements.) All brazed connections shall be cleaned of all residual flux. Protection shall be provided by a moisture-proof paint conforming to the requirements of FAA-STD-012 or shall be sealed with a silicone or petroleum-based sealant to prevent moisture from reaching the bond area. Bonds protected by conductive finishes (alodine, iridite, et.al) shall not require painting to meet the requirements of this standard.

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3.9.5.2 Vibration. Bonds shall be protected from vibration-induced deterioration by assuring that bolts and screws employ lock washers, self-locking nuts, or jam nuts that are properly tightened and rivets that are securely seated.

3.9.6 Bonding across shock mounts. Bonding straps installed across shock mounts or other suspension or support devices shall not impede the performance of the mounting device. They shall be capable of withstanding the anticipated motion and vibration requirements without suffering metal fatigue or other failures. Extra care shall be utilized in the attachment of bonding strap ends to prevent arcing or other forms of electrical noise generation from strap movement.

3.9.7 Enclosure bonding. Subassemblies and equipment shall be directly bonded, whenever practical, at the areas of physical contact with the mounting surface.

3.9.7.1 Subassemblies. Subassemblies shall be bonded to the chassis utilizing the maximum possible contact area. All feedthroughs, filters, and connectors shall be bonded around the periphery to the subassembly enclosure to maintain shield effectiveness. Covers shall exhibit intimate contact around their periphery, and contact shall be achieved and maintained through the use of closely spaced screws or bolts, or the use of resilient conductive gaskets, or both.

3.9.7.2 Equipment. The chassis or case of an equipment shall be directly bonded to the rack, frame, or cabinet in which it is mounted. Flange surfaces and the contact surface on the supporting element shall be cleaned of all paint or other insulating substances in accordance with the requirements of paragraphs 3.9.3 through 3.9.3.2. Fasteners shall maintain sufficient pressure to assure adequate surface contact to meet the bond resistance requirements in para. 3.9.11. Tinnerman nuts and sheet metal screws shall not be used for fasteners. If equipment must remain operational when partially or completely withdrawn from its mounted position, the bond shall be maintained by a moving area of contact or by the use of a flexible bonding strap. Except when necessary to maintain bonding during adjustments, maintenance, or when other constraints prevent direct bonding, the use of straps shall be avoided. Mechanical designs shall emphasize direct bonding.

3.9.8 Connector mounting. Standard MIL-SPEC-type connectors, shell-type connectors and coaxial connectors shall be mounted so that intimate metallic contact is maintained with the panel on which it is mounted. Bonding shall be accomplished completely around the periphery of the flange of the connector. Both the flange surface and the mating area on the panel shall be cleaned in accordance with paragraphs 3.9.3 through 3.9.3.2. All nonconductive material shall be removed from the panel as illustrated in Figure 4, "Bonding of Connectors to Mounting Surface." After mounting of the connector, the exposed area of the panel shall be repainted or otherwise protected from corrosion in accordance with paragraphs 3.9.5 and 3.9.5.1.

3.9.9 Shield terminations. Cable shields shall be terminated in the manner specified by paragraphs 3.8.2.6, 3.8.2.7, and 3.8.3.2. Shields of coaxial cables shall be fastened tightly to the cable connector shell with a compression fitting or soldered connection. The cable shall be able to withstand the anticipated use without becoming noisy or suffering a degradation in shielding efficiency. Coaxial connectors shall be of a material that is corrosion resistant in keeping with requirements of FAA-G-2100. Low frequency shields shall be soldered in place or, if solderless terminals are used, the compressed fitting shall afford maximum contact between the shield and the terminal sleeve. Shield pigtails shall be less than 1 inch from the point of

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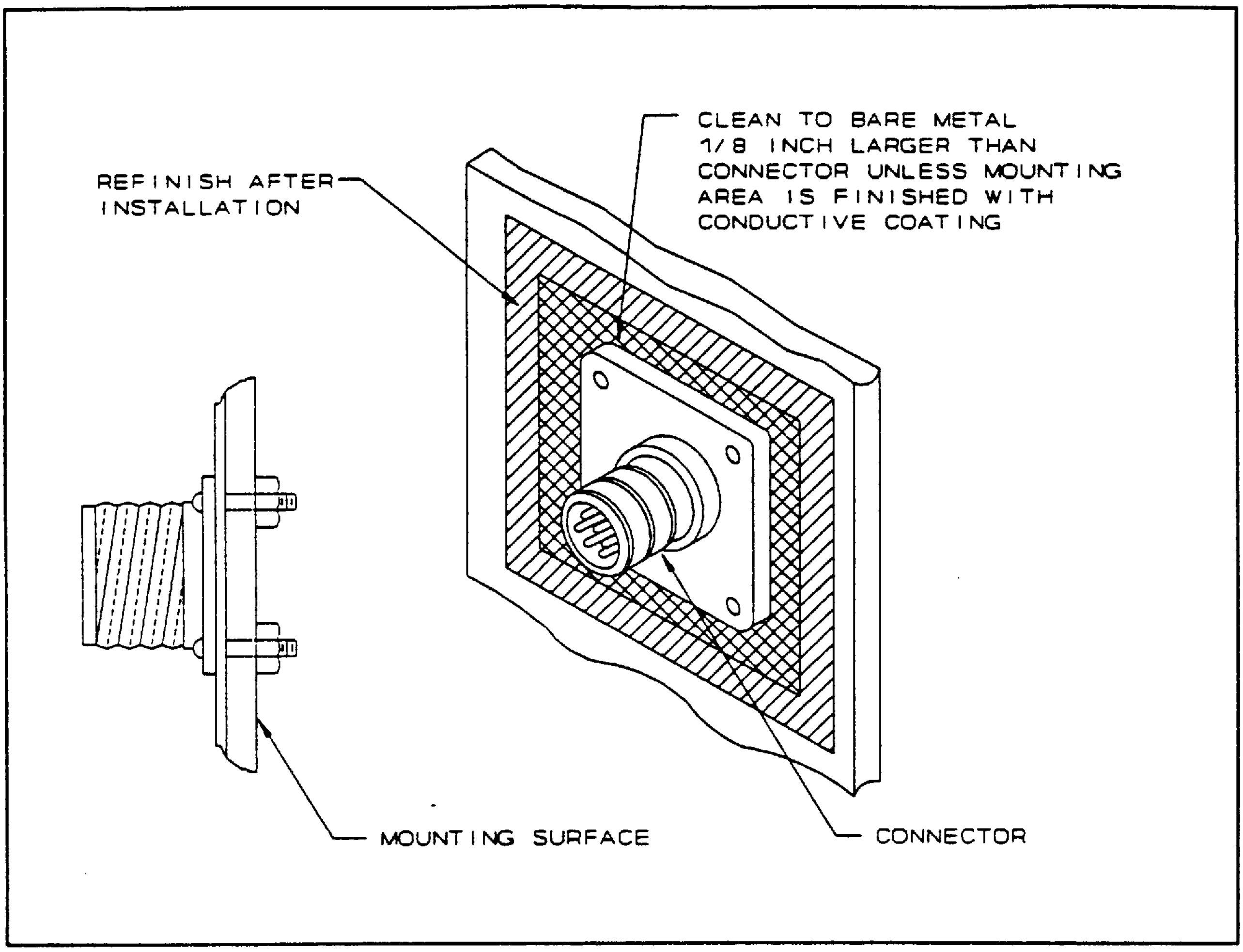

Figure 4. Bonding of Connectors to Mounting Surface

breakaway from the center conductors of the cable.

3.9.10 RF gaskets. Conductive gaskets shall be made of corrosion resistant material, shall offer sufficient conductivity to meet the resistance requirements of para. 3.9.11, and shall possess adequate strength, resiliency, and hardness to maintain the shielding effectiveness of the bond. The surfaces of contact with the gasket shall be smooth and free of insulating films, corrosion, moisture, and paint. The gasket shall be firmly affixed to one of the bond surfaces by screws, conductive cement, or other means which do not interfere with the effectiveness of the gasket; or a milled slot shall be provided that prevents lateral movement or dislodging of the gasket when the bond is disassembled. Gaskets shall be a minimum of 1/8 inch wide and of a reusable type. The gasket as well as the contact surfaces shall be protected from corrosion.

3.9.11 Bond resistance. All bonds between conductors whose primary function is to provide a path for power, control, and signal currents shall have a maximum DC resistance of 1 milliohm. The resistance across joints or seams in metallic members required to provide electromagnetic shielding shall be 2.5

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milliohms or less. Where high-frequency or high-speed signals are used, these bonds shall also consider minimizing AC impedance.

3.10 Shielding requirements.

3.10.1 General. The equipment design shall incorporate component compartments and overall shields as necessary to meet the electromagnetic susceptibility and emission requirements of MIL-STD-461 as required by NAS-SS-1000. In addition, the design shall provide the shields necessary to protect personnel as required by para. 3.11 from hazardous voltages, high level electromagnetic fields, and x-rays which may be generated by equipment.

3.10.2 Electromagnetic environment control. Shielding shall be integrated with other basic interference control measures such as filtering, wire routing, cable and circuit layout, signal processing, spectrum control, and frequency assignment to achieve the highest operational reliability of the equipment. Implementation procedures necessary to achieve the required filtering and shielding shall be detailed in the control plan described in para. 4.2 to include material requirements, shield configurations, placement and installation limitations, gasket utilization, filter integration, aperture control, bonding and grounding requirements, and wire routing and circuit layout constraints.

3.10.2.1 Materials. Shields shall be constructed of a material that provides the required degree of signal suppression without incurring unnecessary expense and weight. In the choice of the material, the amplitude and frequency of the signals to be attenuated, the characteristics of the electromagnetic field of the signal (i.e., the signal being coupled via inductive, capacitive, or free space means), configuration and installation constraints, and corrosion properties shall be considered.

3.10.2.2 Gaskets. Conductive gaskets conforming to para. 3.9.10 shall be utilized at joints, seams, access covers, removable partitions, and other shield discontinuities to the extent necessary to provide interference-free operation of the equipment under normal use and environmental conditions. Finger stock used on doors, covers, or other closures subject to frequent openings shall be installed in a manner that permits easy cleaning and repair.

3.10.2.3 Filter integration. Filters on power, control, and signal lines shall be installed in a manner that maintains the integrity of the shield. Powerline filters shall be completely shielded with the filter case grounded in accordance with para. 3.8.11. Filters for control and signal lines shall be placed as close as possible to the point of penetration of the case to avoid long, unprotected paths inside the equipment.

3.10.2.4 Control of apertures. Unnecessary apertures shall be avoided. Only those shield openings needed to achieve proper functioning and operation of the equipment shall be provided. Controls, switches, and fuse holders shall be mounted so close metal-to-metal contact is maintained between the cover of housing of the devices and the case. Metal control shafts shall be grounded in accordance with para. 3.8.10.1. Where nonconductive control shafts are necessary, a waveguide-below-cutoff metal sleeve peripherally bonded to the case shall be provided for the shaft. The cutoff frequency for the circular waveguide shall be considerably higher than the equipment operating frequency. The length of the sleeve shall be no less than four times its diameter. Pilot lights shall be filtered or shielded as needed to maintain the required degree of shielding effectiveness. Ventilation and drainage holes shall not penetrate RF compartments if at all possible. If necessary, ventilation and drainage holes shall utilize waveguide-below-cutoff honeycomb or other

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appropriate screening. Care shall be taken to assure that honeycomb and screens are well bonded to the shield completely around the opening.

3.10.2.5 Bonding and grounding of compartment shields. All shields shall be grounded. Bonding shall be accomplished in accordance with paragraphs 3.9 through 3.9.11.

3.10.2.6 Wire and cable routing. The routing and layout of wires and cables shall be performed in a manner that does not jeopardize the integrity of the equipment shield. High-level signals shall be routed as far as feasible from low level signals. Powerlines and control lines subject to large transients shall be routed away from sensitive digital or other susceptible circuits. Shielded cables shall be used for either extremely low- or high-level signals. Cable shields shall be grounded in accordance with the requirements of paragraphs 3.8.2.6, 3.8.2.7 and 3.8.3.2.

3.10.2.7 Circuit layout. Circuit layout techniques that provide maximum practical separation between high- and low-level signals shall be employed. High level pulse, switching and power circuits shall be separated from low level digital, analog and similar sensitive circuits. Sensitive conductors internal to circuits shall not be laid out parallel to unshielded wires and cables subject to external interference. Shield terminations and connections to the signal reference ground shall be as short as practical.

3.11 Personnel protection requirements.

3.11.1 General. Personnel protection considerations shall be in accordance with the NEC, para. 3.8.6 herein and FAA-G-2100.

3.12 Control of static electricity.

3.12.1 General. The circuits and components used by electronic equipment, computers, and data processing equipment that are subject to damage by static electricity or electrostatic discharge (ESD) shall be protected in accordance with the requirements herein.

3.12.2 Controlled areas. Operation, storage, repair and maintenance spaces used for circuits and equipment subject to damage by static electricity shall be designated as ESD controlled areas.

3.12.3 Circuit and equipment design. The design, layout and packaging of circuits and equipment shall incorporate methods and techniques to reduce their susceptibility to ESD. Electronic circuits and equipment shall be desensitized to ESD by eliminating conductive paths, grounding or insulating paths, and by suppressing conducting paths of discharge. Circuit boards shall be designed with maximum ground plane coverage. Protective coatings for circuit boards shall be selected for their insulating properties and protection against ESD. Integrated circuits and other components inherently susceptible to ESD and having an exposed conductive path for ESD shall be protected by a capacitor, SAS, or a varistor. Protective components shall be installed as close as possible to ESD susceptible components. In the installed and operating configuration, equipment enclosures, controls, meters, displays, test points, et.al., shall withstand a static discharge of 15,000 volts through an International Electrotechnical Committee (IEC) "human body model" (150 picofarad capacitor in series with a 150 ohm resistor) without operational upset or damage to any component or part.

3.12.4 Packaging and storage. All components, circuits and assemblies subject to damage by ESD shall be packaged, shipped and maintained in transparent static shielding bags or packages when not installed. Components

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which may be susceptible to EMI shall also be provided with protective packaging as required.

3.12.5 Work surfaces. Test, repair and maintenance stations and other work surfaces and their associated standing space shall be covered with semiconducting material designed to protect components and assemblies from ESD. A small grounded plate shall also be provided for the positive discharge of personnel, tools and test leads prior to direct contact with components and assemblies.

3.12.6 Tools and accessories. All tools and workbench accessories shall be selected to minimize discharge and damage to components and assemblies.

3.12.7 Furniture and upholstery. All upholstery and chair covering material on controlled spaces shall be of material with a low propensity to retain electrical charge, and static electricity. Chairs and upholstered furniture shall have metal frames. Stationary feet shall be conductive (uninsulated). Caster or rollers on chairs and movable furniture shall be steel, conductive rubber, or conductive plastic.

3.12.8 Shoes and clothing. The manufacturer of the equipment shall provide recommendations for shoes, clothing, uniforms, et al. If necessary, anti-static sprays shall be provided for operations and maintenance personnel.

3.12.9 Printers. High speed printers shall have grounded metal tinsel rope braid draped across the paper output path to minimize static charge.

3.12.10 Ion generation. Ion generators may be used for small areas or spaces when cost effective in comparison with other static control measures. They shall be of a type which produces both positive and negative ions.

4. QUALITY ASSURANCE PROVISIONS

4.1 Electromagnetic compatibility and quality assurance.

4.1.1 General. A comprehensive plan for the application of various sections of this document is required to assure the compatible operation of equipment in complex systems. Additional considerations of this section shall be implemented to reduce susceptibility and emissions of equipment.

4.2 Requirements. The emission and susceptibility limits contained in MIL-STD-461 shall be applied unless otherwise specified. An EMI Control and Test Plan shall be developed in accordance with MIL-HDBK-237 to assure compliance with the applicable requirements. The plan shall include a verification matrix to track the satisfaction of requirement by test, analysis or inspection. Analyses or tests performed as part of para. 3.4 shall be identified in this plan.

4.3 Approval. Control Plans and Test Plans shall be submitted to the Contracting Officer for approval.

5. PREPARATION FOR DELIVERY

5.1 General. Equipment which may be damaged by ESD or EMI shall be protected as described in para. 3.12.4.

6. NOTES

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6.1 Definitions.

6.1.1 Bond. The electrical connection between two metallic surfaces used to provide a low-resistance path between them.

6.1.2 Bond, direct. An electrical connection utilizing continuous metal-to-metal contact between the members being joined.

6.1.3 Bond, indirect. An electrical connection employing an intermediate electrical conductor between the bonded members.

6.1.4 Bonding. The joining of metallic parts to form an electrically conductive path which assures electrical continuity and the capacity to safely conduct any current imposed between the metallic parts.

6.1.5 Bonding jumper. A reliable conductor to assure electrical conductivity between metal parts required to be electrically connected.

6.1.6 Brazing. A joining process using a filler metal with working temperature above 800°F, but below the melting point of the base metal. The filler material is distributed by capillary action.

6.1.7 Building. The fixed or transportable structure which houses personnel and equipment and provides the degree of environmental protection required for reliable performance of the equipment.

6.1.8 Cabinet. A protective housing or covering for two or more units or pieces of equipment. A cabinet may consist of an enclosed rack with hinged doors.

6.1.9 Case. A protective housing for a unit or piece of electrical or electronic equipment.

6.1.10 Chassis. The metal structure that supports the electrical or electronic components which make up the unit or system.

6.1.11 Clamp voltage. The voltage that appears across transient suppressor terminals when the suppressor is conducting transient current.

6.1.12 Conductor, bare. A conductor having no covering or electrical insulation.

6.1.13 Conductor, insulated. A conductor encased within material of composition and thickness that is recognized by the National Electrical Code as electrical insulation.

6.1.14 Crowbar. In surge protection devices, the term "crowbar" refers to a method of shorting a surge current to ground. This method provides protection against more massive surges than other types, but lowers the voltage below the operational voltage of the electronic equipment causing noise and operational problems. It also permits a follow current which can cause damage.

6.1.15 Electromagnetic interference (EMI). Any emitted, radiated, conducted or induced voltage which degrades, obstructs, or repeatedly interrupts the desired performance of electronic equipment.

6.1.16 Equipment grounding conductor. The green insulated conductor run with the phase and neutral conductors used to connect non-current-carrying metal parts of equipment, raceways, and other enclosures to the system grounded

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conductor and/or to the grounding electrode conductors at the main service disconnect means or at the service of a separately derived system.

6.1.17 Equipment, unit or piece of. An item having a complete function apart from being a component of a system.

6.1.18 Facility ground system. Consists of the complete ground system at a facility including the earth electrode system, electronic multipoint ground system, electronic single-point ground system, lightning protection system, grounding electrode conductors, and equipment grounding conductors.

6.1.19 Ground. A conducting connection, whether intentional or accidental, between an electrical circuit or equipment and the earth or to some conducting body that serves in place of the earth.

6.1.20 Grounded. Connected to earth or to some conducting body that serves in place of the earth.

6.1.21 Grounded conductor. A system or circuit conductor that is intentionally grounded at the service disconnecting means and at the transformer serving the facility. This conductor is the neutral conductor for the power systems.

6.1.22 Grounded, effectively. Permanently connected to earth through a ground connection of sufficiently low impedance and having sufficient current carrying capacity so that ground fault current which may occur cannot build up to voltages dangerous to personnel.

6.1.23 Grounding conductor. A conductor used to connect equipment or the grounded circuit of a wiring system to the grounding electrode system.

6.1.24 High frequency. Includes all electrical signals at frequencies greater than 100 kilohertz (kHz). Pulse and digital signals with rise and fall time of less than 10 μs are classified as high-frequency signals.

6.1.25 Landline. Any conductor, line or cable installed externally above or below grade to interconnect electronic equipment in different facility structures or to connect externally mounted electronic equipment.

6.1.26 Low frequency. Includes all voltages and currents, whether signals control, or power, from DC up to and including 100 kHz. Pulse and digital signals with rise and fall times of 10 μs or greater are considered to be low-frequency signals.

6.1.27 Electronic multipoint ground system. An electrically continuous network consisting of interconnected ground plates, equipment racks, cabinets, conduit junction boxes, raceways, duct work, pipes, copper grid system, and other non-current-carrying metal elements. It includes conductors, jumpers and straps that connect individual items of electronic equipment to the electronic multipoint ground system.

6.1.28 Overshoot voltage. The fast rising voltage that appears across transient suppressor terminals before the suppressor turns on (conducts current) and clamps the input voltage to a specified level.

6.1.29 Rack. A vertical frame in which one or more units of equipment are mounted.

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6.1.30 Reference plane or point, electronic signal. The conductive terminal, wire, bus, plane, or network which serves as the relative ground reference for all associated electronic signals.

6.1.31 Reverse standoff voltage. The maximum voltage that can be applied across transient suppressor terminals with the transient suppressor remaining in an OFF (non-conducting) state.

6.1.32 Shield. A housing, screen, or cover which substantially reduces the coupling of electric and magnetic fields into or out of circuits, or prevents accidental contact of objects or persons with parts or components operating at hazardous voltage levels.

6.1.33 Electronic single-point ground system. A signal reference network which provides a single-point reference in the facility for equipment that requires single-point grounding. The single-point ground system is laid out in a manner that minimizes stray currents, and magnetic interference. It consists of conductors, plates and equipment terminals, all of which are isolated from any other grounding system except at the main ground plate. This main ground plate is connected to the earth electrode system and serves as the central tie point between the single-point ground point system, the multipoint ground system, and the earth electrode system.

6.1.34 Structure. Any fixed or transportable building, shelter, tower, or mast that is intended to house electrical or electronic equipment or otherwise support or function as an integral element of the air traffic control system.

6.1.35 Transient suppressor. Component(s), device(s) or circuits designed for the purpose of attenuating and suppressing conducted transient and surge energy to protect facility equipment. At the service disconnecting means, the term "arrester" is generally used instead of transient suppressor.

6.1.36 Turn-on voltage. The voltage required across transient suppressor terminals to cause the suppressor to conduct current.

6.1.37 Surge. An overvoltage of short duration occurring on a power line. Surges may be caused by lightning or switching events.

6.1.38 Transient. An overvoltage or overcurrent pulse on a signal, control, or data line. Transients are typically a lightning related phenomenon.

6.1.39 Susceptibility level. The electronic equipment susceptibility level is the least of the damage, degradation, or upset levels considering all electronic components potentially affected by conducted transients.

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6.2 Acronyms and abbreviations. The following are acronyms and abbreviations contained within this standard.

A	-	ampere(s)
AC	-	alternating current
AWG	-	american wire gauge
cm	-	centimeter(s)
DC	-	direct current
e.g.	-	for example
EMI	-	electromagnetic interference
ESD	-	electrostatic discharge
et al.	-	and others
FAA	-	Federal Aviation Administration
Hz	-	hertz
i.e.	-	that is
IEC	-	International Electrotechnical Committee
kHz	-	kilohertz
m	-	meter(s)
NEC	-	National Electrical Code
NFPA	-	National Fire Protection Association
RF	-	radio frequency
SAS	-	silicon avalanche diode suppressor
UL	-	Underwriters' Laboratories
μs	-	microsecond(s)
V	-	volt(s)

6.3 Guidelines. Engineering design guidelines are provided for grounding, bonding, shielding, and transients protection in FAA Orders 6950.19 and 6950.20. Guidance for EMI protection is in MIL-HDBK-253, and for Static Electricity in NFPA 77, DOD-HDBK-263 and DOD-STD-1686.

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